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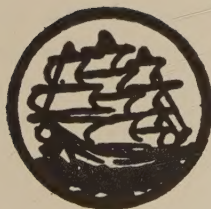
CONTENTS

SATOH, Y.: Relation between secondary undulations of tides and oceanic waves with its application for a coastal surge monitoring	1
SAWARA, T.: On the sea surface temperature in the East China Sea for the years 1953-1972	17
NAGASAKA, K.: Newly-built research vessel Shumpu-Maru III	37
IIDA, H. and K. KATAGIRI: Abnormal spreading of cold water along the east coast of Honshu Island in February, 1974	41

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Relation between secondary undulations of tides and oceanic waves with its application for coastal surge monitoring

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Abstract: As is well noticed, secondary undulations of tides may probably appear in any tidal station, most of which turn out to be long waves of about 2 to 3 min. period, so-called surf beats. Here, a simple method is proposed for coastal surge monitoring by the use of these secondary undulations with the aid of the relations between the incoming swells and the long waves. Experimental observations were carried out at Miyako tidal station and the results of analysis were applied to coastal surge problem in the bay of Miyako.

1. Introduction

In any tidal records some secondary undulations, which may often look as pulsations, would probably appear frequently. TERADA (1912) paid attention to such undulations first about sixty years ago.

NAKANO (1939) reexamined these secondary undulations of tides caused by a cyclone and found that these undulations generally begin to be significant several hours before the arrival of a cyclone, while neither wind bursts nor pressure changes in the vicinity of the tidal station. The direct cause of these undulations seems to be chiefly due to the long waves produced by some microbarometric disturbances near the central region of a cyclone distant from the station.

ADACHI (1937) found very regular oscillations with a period of nearly 2 min. in the tidal records of Fukae, Osaka Bay for Sept. 11, 1937, under rough sea condition. It is probably the first time in our country that the secondary undulations of tides were observed by a rapidfeed recording system.

In the U.S.A., MUNK (1949) found long waves of 2 to 3 min. period with a tsunami recorder and named them "surf beats" for the reason that the long waves might be brought up by irregularity of an excess of mass carried landwards by the group of swells.

On the Atlantic coast of England, long waves of 1 to 5 min. period were also caught by TUCKER (1950), who wondered why a high group of incoming swell is

associated with a negative pulse of pressure reflected from the shore.

The question was solved by LONGUET-HIGGINS and STEWART (1962) with the idea of "radiation stress" which is defined as the excess-momentum flux under the disturbed surface of water.

On the other hand, the best phenomena concerning the oceanic waves have been explained theoretically by YOSHIDA (1950). The 1 to 3 min. waves and the beat of the similar periods may possibly occur when most of energy of shorter waves, sea or swell, is concentrated within a comparatively narrow and finite band the breadth of which is about 1 to 2 sec intervals in the spectrum.

At Hachijo island, DAIDOJI et. al. (1953), UNOKI et. al. (1955) observed some very high waves with the period of about 2 min. accompanied by the wind waves of a typhoon, and at the same island, HATORI (1969) carried out spectral analyses of the oceanic long period waves concerning tsunamis.

Recently, in the rolling motion of sea vessels, MANABE et. al. (1967) too detected three predominant periods including long waves of 3 to 5 min. period.

ICHIYE (1956) made a detailed discussion on the development of secondary undulations of over about 20 min. period in the tidal record accompanied by a typhoon swept along the west coast of Japan.

As is mentioned above briefly, a number of investigations have been made by many authors on the oceanic waves causing the undulations, however, most of their interests seem to be concerning forecasting problems of wave itself or sea-born storm tracking, and instrumentations of wave measurements.

The study of fluctuations of tidal records themselves has never been taken up with the idea of studying surf beat except for seiche phenomena in the bay.

The first attempt, in fact, to use tidal fluctuation as an aid of wave estimation was made by the author in 1957 at the harbour of Matsukawa, Fukushima Prefecture, some case studies of which were reported (SATO, 1957). Recently, an abnormal abrupt increasing of high surges with a period of about 10 sec happened to occur off Miyako.

Some empirical relations between significant waves and fluctuations of tides were obtained (SATO, 1972). Simultaneous observations of tides and waves were carried out for the research both in and outside the well of the tidal station with wave recorders and a portable tide gauge (SATO, 1973, see photo. 1).

As a result, it reveals that the major component of fluctuations of tidal records may be surf beats, the periods of which are generally long enough to be caught easily even by an ordinary tide gauge having a low-pass character. As surf beats

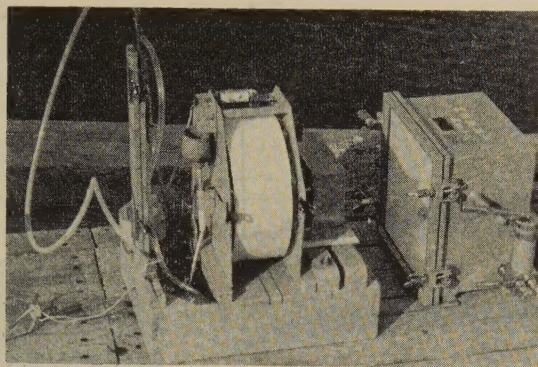


Photo. 1. A portable tide recorder, essentially constructed with a u-tube mercury manometer, a self-recording drum driven by clock (shown on the left side) and a suction pump (on the right).

Time spent in recording a half of the final variation, 3 sec.

are considered to have a relation to the incoming swells causing a coastal surge physically, we can use the fluctuations of tides as an indirect indicator of the height of incoming swells.

In the present paper is proposed a method of making use of an ordinary tide gauge for detecting and monitoring the coastal surges.

2. Constituents of secondary undulations of tides

Fig. 1 shows a typical example of the development of secondary undulations of tides observed in Miyako Bay. The outstanding features of these undulations may usually look as impulse on the ordinary tide gauge recording sheet which is fed at a speed of about 20 mm/hour. This feed speed being so slow that such waves shorter than about 2 min. period can not be identified because of overlap of records themselves, so device for faster feeding, up to about 30 mm/min. (Weihert's seismograph's drum) was attached to an ordinary set as shown in Photo. 2.

Fig. 2 denotes one of the sampled rapidfeed records of tides observed at Kuwagasaki Harbour and the records of swells outside the well of tidal station by a wave recorder with stand pipe through photographic calibration for comparison, and records of swell at the central region of Miyako Bay obtained by an ultrasonic wave

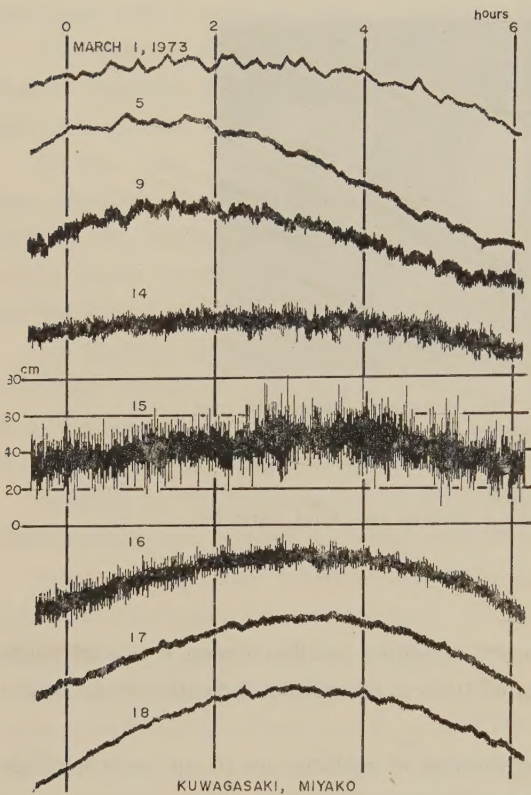


Fig. 1. An example of tide records obtained at Kuwagasaki Harbour, Miyako, showing the development of conspicuous undulations of tides up to about 60 cm in height at their maxima.

meter (up most).

The duration of rapidfeed records of tide and swell (middle) corresponds to shaded band on the ordinary tide record (lowest). It may be quite evident that pulse-like oscillations appearing in a tidal record consist of several sinusoidal waves. From 16 measurements obtained in Miyako Bay during the period of Aug. 1971 to March 1973, three predominant periods were revealed: 8 to 15 sec, 30 to 80 sec and 1.5 to 3.0 min. (see Table 1). Among these periods, the long one of about 2 to 3 min. can be seen invariably in any cases notwithstanding the sea states.

Fig. 3 illustrates some examples of spectra of tidal fluctuations shown roughly by a period vs (amplitude)² relation. Since these examples are of about 90-minute

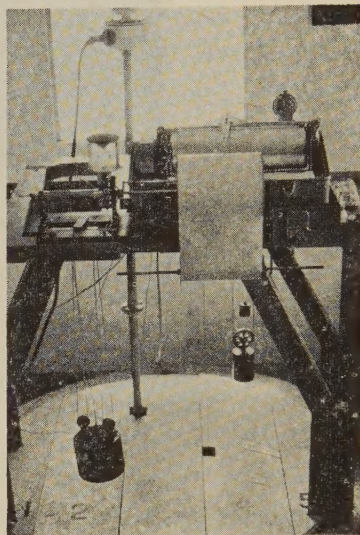


Photo. 2. An attachment to a Foess tide gauge, Weiher's seismograph's drum seen in the foreground and an extended recording pen, made of vinyl.

Y. SATOH: Secondary undulations of tides and oceanic waves

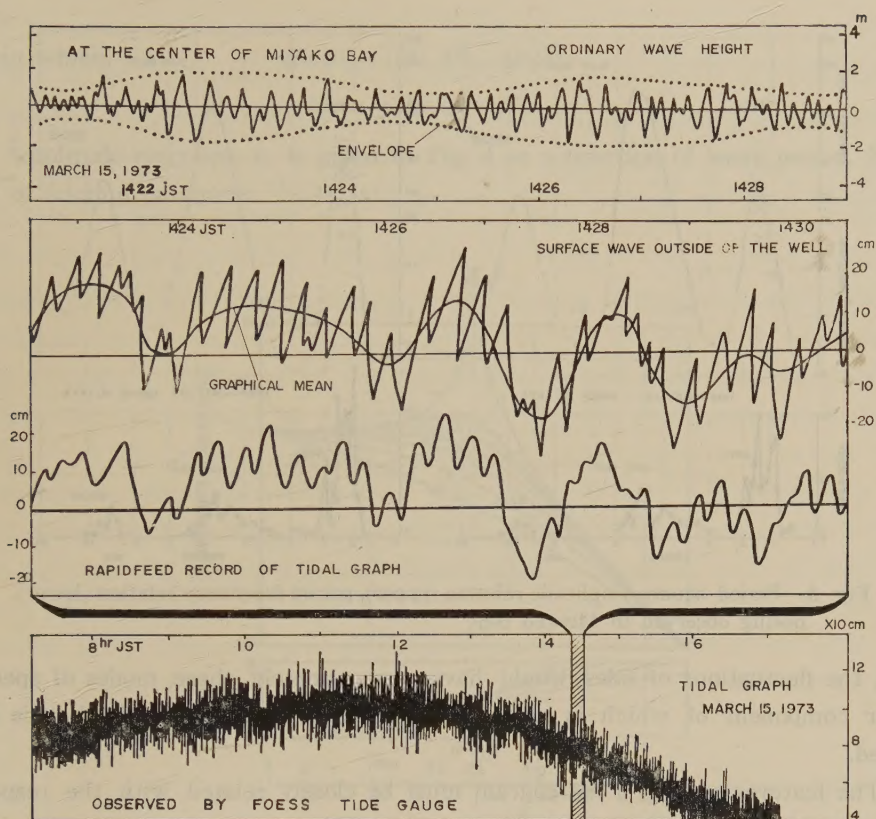


Fig. 2. Comparative records of tides and swells; upper two show the swell records observed at the center of the bay and at the outside of the tide-well, lower two show tide records observed at Kuwagasaki Harbour; the shaded band on the ordinary record (lowest) corresponds to the dulution of the time-elongated one.

Table 1. Predominant periods of tide records observed at Kuwagasaki, Miyako.

Date	1	2	3	4	sea condition
1971 Aug. 31	8.3 sec	40.5 sec	2.1-2.3 min		rough
Sept. 1	9.5	46	2.1		"
1	10.0	58	2.5-3.1		"
2	10.2	45	2.1-2.3		"
1972 Jan. 14	13.4	82	2.5-2.7		"
May 18			2.4-2.7		calm
22			2.1-2.5		"
June 5			2.1-2.3		smooth
23			2.1-2.3		calm
July 20			2.3-2.5		"
Aug. 4			1.5-2.3		smooth
20		25-35	2.6		moderate
1673 Jan. 30	9.0		1.5-2.0		smooth
Mar. 15	8-10		1.5-2.0	4-7 min	rough
15	14.2-15.0		2.0-2.4	3.5-5.5	"
16	14.8-15.2		1.7-3.0	5.5-6.5	"
	13.7-14.3				"

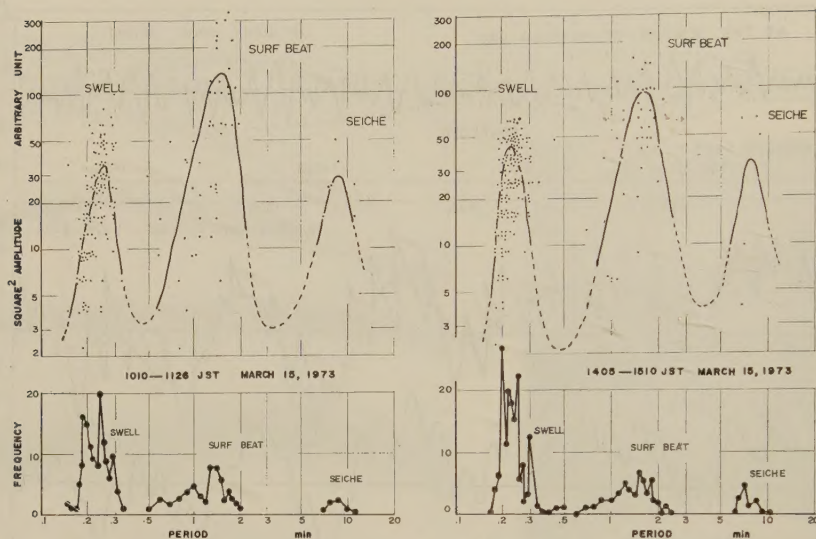


Fig. 3. Period square-amplitude relation (upper), period-frequency relation (lower), being observed in Miyako Bay.

spell, the fluctuations of tides would have approximately three modes of spectra, major component of which is caused by surf beats so far as Miyako Bay is concerned.

The features seen in a mareogram must be closely related with the response characteristics of apparatus used.

3. Frequency response of the tide well as a wave meter

A tide-well is usually designed so as to eliminate high frequencies due to disturbances of the sea surface.

MORIYASU (1952) discussed the rise and fall of water surface in a tide-well as forced oscillations, and obtained a differential equation of motion:

$$\frac{d^2h}{dt^2} + 2k \frac{dh}{dt} + n^2h = n^2H, \quad (1)$$

where, h and H are the height of water above its still surface inside and outside of the well, respectively, k is damping coefficient due to frictional resistance, and n the constant dependent on the dimensions of the well.

Supposing $H = A \cos pt$, the solution becomes

$$h = \phi A \cos(pt - \alpha) + (\text{free oscillation term}) \quad (2)$$

in which,

$$\phi = n^2 / \sqrt{(n^2 - p^2) + 4k^2 p^2}$$

$$\tan \alpha = 2kp / (n^2 - p^2)$$

Amplitude response, ϕ , is given in Fig. 4 as a function of wave period, T and that of friction parameter, $b = 4k^2/n^2$.

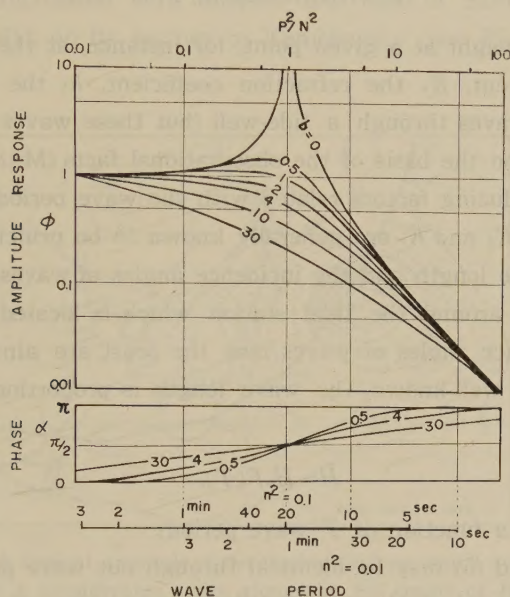


Fig. 4. Frequency response of tide observation well (SATOH, 1972a).

ϕ : amplitude response, b : friction parameter, $b = 4k/n^2$, where, k : damping coefficient, n^2 : constant corresponding to the dimensions of the tide-well, T : wave period.

Usually, a tide-well can seldom be used under such extreme critical conditions as friction being nearly equal to zero or of very high order.

It may therefore be said that a tide-well is of low-pass character for the long period waves over about 60 sec and ϕ is almost unity, while for the shorter waves of less than about 60 sec, e. g., sea or swell, ϕ diminishes logarithmically as the period decreases, we can approximate as follows,

$$\log \phi = -\log(p^2/n^2) = \log n^2 T^2 / (2\pi)^2 \quad (3)$$

Hence, the interrelation between h and H becomes

$$H = \alpha h / T^2, \quad (4)$$

where
$$a = (2\pi)^2 / n^2$$

The incoming waves do not always consist of a single swell but a complex one, and the waves which we want to monitor would not always be what found near the station site, then the aforementioned relation should be rewritten as,

$$H = H_o K_s K_r = \Sigma a_i h_i / T_i^2, \quad (5)$$

where, H_o is wave height at a given point, for instance, at the center of a bay, K_s the shoaling coefficient, K_r the refraction coefficient, h_i the various amplitudes caused by various waves through a tide-well (but these waves are supposed to be all nearly in phase on the basis of the observational facts (MANABE, 1969; SATOH, 1972)) and a_i the reducing factors related with the wave periods, T_i .

In equation (5), K_s and K_r are generally known to be principally related to the depth of water, wave length and the incidence angles of waves (TOYOSHIMA, 1969). The depth of water around the tidal station which is located at a fixed point, is constant, the incidence angles of waves near the coast are almost parallel to the coast line, and as is well-known, the wave length is proportional to the square of wave period, then,

$$H = H_o F(T), \quad (6)$$

where $F(T)$ means a function of T (wave period).

Equations (4) and (6) may be identical through out wave period, consequently, we can apply H_o instead of H , and the following formulas would be given,

$$H = ahT^{-b}, \quad (7)$$

where a and b are constants, the value of b may be equal to 2,

$$\text{or } H = ah^b, \quad (8)$$

where T is assumed as unity.

In equation (4), putting $n^2 = 0.08$, $T = 10$ sec, equation (4) gives $H = 5h$, which has already been applied as an empirical formula for the waves about 1 km off Sokei Beach in the bay of Miyako (SATOH, 1972).

The empirical formula $H = 5h$ is nothing but formula (8).

4. h - H relations obtained from the field observation and their application for hindcasts

On March 11, 1971, a cyclone generated in the East China Sea took its path to NE and moved along the Japanese Islands rapidly, deepened its central pressure during 12-13th, amalgamated with another low east of Sanriku and developed severely during 15-16th on its journey to Kamchatska (see Fig. 5). Accordingly,

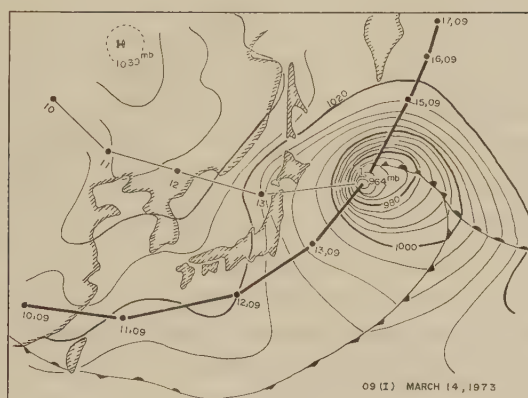


Fig. 5. A typical example of developing cyclone which may often cause a considerable surge along the NE coasts of Japan.

along the east coast of northeast Japan, coastal waves became rough gradually from the evening of 13th, reached their maxima in the daytime of 15th and continued their roaring until the noon of 16th.

Fortunately, by the kindness of the MIYAKO HARBOUR CONSTRUCTION OFFICE of the 2nd REGIONAL PORT and HARBOUR CONSTRUCTION BUREAU and the wave observation station of IWATE PREFECTURE, simultaneous observations of waves and tides were obtained both at the bay of Miyako and Shimanokoshi for March 13-16th, 1971. The instruments used at Miyako, were an inverted ultrasonic wave gauge set at the center of the bay about 1000 m distant from the tidal station where a Foess tide gauge is installed. At Shimanokoshi a pressure type wave gauge was set about 250 m off a Hydrological Institute No. 2-type tide gauge.

Fig. 6a shows the development of significant wave height, H , the envelope of

fluctuation of tide, h , and the significant wave period, T , at Shimanokoshi, and Fig. 6b and 6c denote h - H relations plotted on a log-log scale for Shimanokoshi and Miyako, respectively.

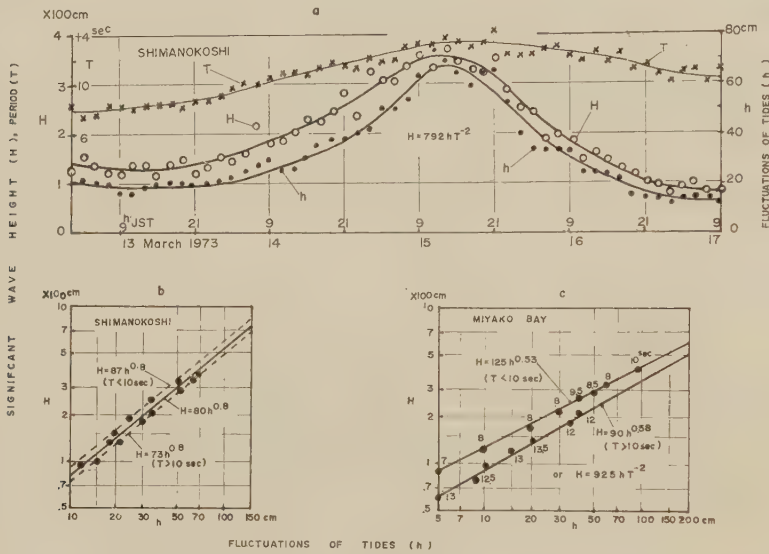


Fig. 6. a: Development of the significant wave height (H), the envelope of the fluctuation of tide (h) and the significant wave period (T) at Shimanokoshi, and b and c: h - H relations plotted on a log-log scale for Shimanokoshi and Miyako, respectively.

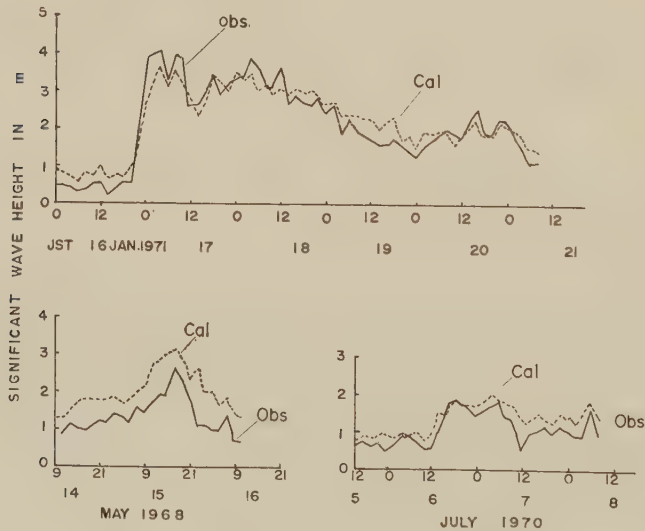


Fig. 7. Comparison of calculated wave height (broken line) with observed significant wave height (solid line) at the center of Miyako Bay.

and Miyako, respectively.

From these figures, reasonable h - H relations corresponding to the response of tide-well can be deduced graphically, some of which are printed in the same figures, and resultants of hindcasts will be seen in Fig. 7. It may be said that the hindcast of significant wave heights does not appear to be quite satisfactory but to be enough to follow its tendencies.

5. Surf beats as the principal cause of coastal long waves

Surf beats, the long waves of 1 to 5 min. period, are generally invisible because their amplitudes are small compared to their wave length, but are evidently caught by such a simple apparatus as ours. What is causing such beats of surf? A lot of investigations about the features of long waves on and around the coast, have been made by many authors as is briefed in the introduction. The explanations of their cause may be divided chiefly into two categories. One is that surf beat will be brought up by oceanic waves with their own nature an inner-source hypothesis and the other is that surf beat is a dispersion of waves caused by microbarometric disturbances around the center of a cyclone, so to speak, an outer-source hypothesis. MUNK (1949) at the head of them, TUCKER (1950), YOSHIDA (1950), LONGUET-HIGGINS et. al. (1962), belong to the former group, and TERADA (1912), NAKANO (1939), WILSON (1957) and MANABE et. al. (1967) to the latter. Moreover, edge waves or trapped waves may take some parts in the birth and dispersion of surf beats (NAKAMURA et. al. 1961).

As each of these explanations seems to be able to verify each of the specific features of surf beats well, the cause of surf beats may probably lie both on the ocean and near the coast.

Since a tide gauge is generally installed ashore, tidal oscillation should be much affected by bottom topography near the coast and the form of coast line; mutual interference caused by wave refraction, diffraction or reflection, and selective resonance owing to seiches characteristic to individual bays or a harbours. For example, refraction diagrams are shown in Fig. 8, for the harbour of Kuwagasaki, Miyako city, where the tidal station is sited at the breakwater opposite a pier which may considerably reflect the refracted waves.

By the suggestion of LONGUET-HIGGINS and STEWART's paper on radiation stress, the amplitude of the surf beat, as a long wave at the point of reflection, would be given as follows:

$$H_r = -\frac{1}{3} \frac{C_r g a^2}{q^2 h^2 \sqrt{gh}},$$

where, H_r is surface elevation at the reflection point, g the gravitational acceleration, q the wave frequency, h the depth of water, a the wave amplitude and C_r the coefficient of reflection. Then, the long wave amplitude, H_r , is proportional to the square of the envelope of the incoming swell and increases negatively as the depth of water, h , diminishes. From the reason, the surf beats observed by such an ordinary tidal station, should be used as an indicator of incoming swells, which may crash out and become coastal surges.

6. Local seiches responsive to the incoming long waves

At the harbour of Kuwagasaki, oscillations with the period of 2 to 3 min. appear continuously although their amplitude becomes invisibly small, while the period of the oscillations changes a little as that of incoming swells changes. Isn't the major period of 2 to 3 min. a proper oscillation of the Kuwagasaki harbour?

YOSHIDA (1950) has already clarified the fact that the 1 to 3 min. waves, especially when the period of free oscillations of a bay or harbour happen to coincide with the period of the long waves, the resonanced amplitude must be greater. However, any affirmative result as related to the Miyako Bay, has not been obtained so far.

Discussions are as follows:

(1) As the Miyako Bay is roughly V-shaped, facing NE, with dimensions of 10 km long and 4 km wide at the mouth, and the mean depth of about 22 m, the period of free oscillations with a single node becomes about 45 min. by MERIAN's formula, and for the double nodes, about 15 min. while the seiche of about 23 min. is more popular in the bay. Generally speaking, the seiches arising from the dimensions of the bay of Miyako, should have a period far longer than that of the long waves in question.

(2) Kuwagasaki harbour is nearly diamond-shaped; its longer diameter is 750 m and shorter one is 600 m, and the maximum depth is 9 m around the entrance of 230 m wide. The depth decreases gradually towards the head of the harbour and the mean depth is about 6 to 7 m (Fig. 8B). As to the oscillation of this harbour, SAKASHITA (1972), by means of MERIAN's formula, has obtained a period of 5 min. for the lateral seiche, whereas the longitudinal one is calculated as 6 to 6.5 min.

If we assume this harbour as a bowl-shape (NOMURA, 1933), with its diameter,

$2a=600$ m, depth at the center, $h=9$ m, the period of free oscillations, T , would be about 2.4 min. by LUMB's formula,

$$T = \frac{2\pi a}{\sqrt{2gh}}$$

Assume an egg-shaped area linearly inclined downwards to the mouth (HIDAKA, 1931), one would have 2.9 min. from the formula,

$$T = \frac{2\pi a}{1.66\sqrt{gh}}$$

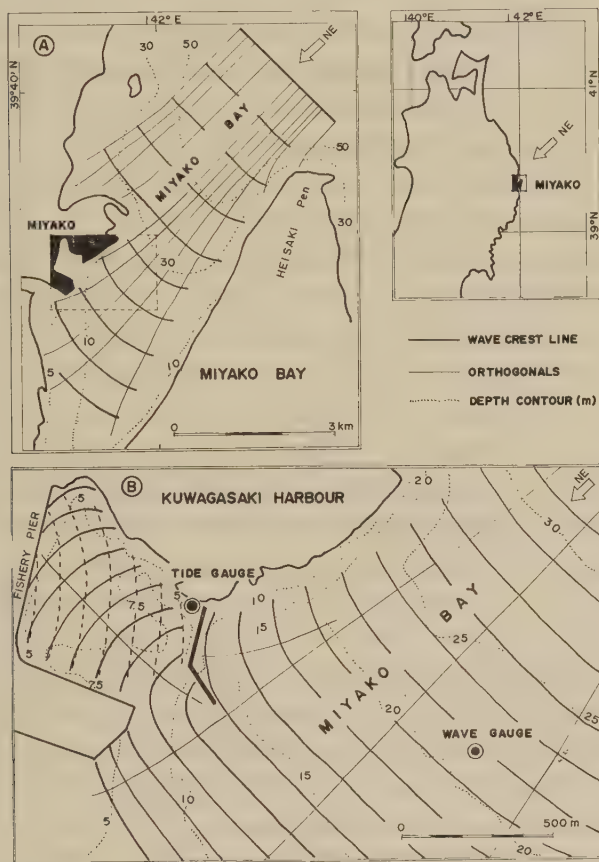


Fig. 8. Refraction diagrams for a single wave (whose period is 11 sec) approaching from NE direction towards Miyako Bay.

In Fig. A, crest interval means five wave-lengths, while Fig. B one wave-length. Dashed lines in Fig. B denote the reflection-wave pattern which may form when the incoming waves are assumed to be reflected merely by the pier opposite the entrance of Kuwagasaki Harbour.

Then, the above-mentioned period of around 3 min. can be explained. However, no experimental evidence supporting any of the above assumptions has yet been obtained. The similar periods, 2 to 3 min., have also been observed at other points in and around the Miyako Bay through experimental observations of tides with a portable set of recorder as mentioned before.

7. Concluding remarks

It is examined whether an ordinary tide gauge could serve as a coastal surge monitor or not. As a result, the ordinary set, e. g. Foess tide gauge can be used as an indirect indicator of coastal surges.

The reasons are summarized as follows:

- (1) Pulse-type fluctuations of tidal records would generally made up of about three groups of waves, swells, surf beats and seiches.
- (2) Among these components of waves, surf beats may be the most favorable for coastal surge monitoring and may probably appear most predominantly, because the shorter waves, sea and swell, would largely be reduced by the damping effect of the tide-well, and the longer waves, seiches characteristic of the bay or harbour, can be distinguished from others, in general.
- (3) Surf beats whose periods are about 2 to 3 min. or the waves with similar periods would be apt to appear as near as the coast owing to their own nature of oceanic waves or their behaviours ashore originated along the coast as being suggested by YOSHIDA (1950) and LONGUET-HIGGINS et. al. (1962).
- (4) These features can be seen more or less in any shore notwithstanding the sea states.
- (5) In general, the tide recorders including an ordinary tide well type tide gauge are of low pass character enough to pass such waves of over about 1 to 2 min. Consequently, an ordinary tide gauge would serve as an indicator of the incoming waves through the "swell-surf beat relation", indirectly.

The following studies are desirable in future:

(1) Demerits

With a tide gauge alone, reliable wave data can not be obtained. The elevation of tidal fluctuations against the swell heights must be checked once by other available method.

(2) Merits

A wave gauge is generally more expensive than a tide gauge, whereas the

ordinary type tide gauges are now coming into wide use, for measurements of astronomical tides. The tide gauges are also available for indirect indicators of incoming swells.

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検潮記録に現われる二次振動と波浪

——検潮記録による沿岸波浪の監視——

佐 藤 義 正

(宮古測候所)

一般に、検潮記録には、一見パルス状に見える二次振動を伴っており、その振幅は、時として数 10 cm に達することがある。この振動は、早回し記録をとって調べてみると、およそ三つの卓越波動群から成り立っていることがわかった。すなわち、主体となるものは、2~3 min 程度の、いわゆるサーフビートであり、これに、港湾局地の固有振動つまりセイシュと、検潮器の特性に応じて出現するウネリの一部である。本来、サーフビートとウネリとの間には、サーフビートの成因に関連して、ウネリの周期・スペクトル構成・波高(エネルギー)、沿岸の水深などを介して、相互に対応関係がある。

他方、通常の検潮器は、周期およそ 1~2 min 以上の長波に対するローパス特性を持っているので、周期 2~3 min のサーフビートは容易に捕捉できる。したがって、検潮記録から、長波(サーフビート)を検知することによって、間接的に短波(沿岸波浪)の監視が可能である。岩手県宮古湾における試用テストは、実用上じゅうぶな成果を示した。

ただし、間接計測(監視)の欠点は、各地における長波(サーフビート)の出現の程度が、検潮所の立地条件、検潮器の周波数特性などによって異なるので、各個に点検が必要なことである。

On the sea surface temperature in the East China Sea for the years 1953-1972

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Abstract: The mean sea surface temperature in the East China Sea was calculated at the grid points of one-degree mesh and half-degree mesh based upon the "The Ten-day Marine Report of the East China Sea" for 1953-1972 and some statistical discussion was carried out. Resulted are as follows:

(1) The maximum sea surface temperature appeared in August in the whole region of the East China Sea. On the other hand the occurrence of the minimum temperature was in February in Kuroshio type water and in March in the cold water area on the continental shelf.

(2) The monthly standard deviation of sea surface temperature ranged from 0.3 to 1.8°C and on an average it was smallest in the Kuroshio and largest in the cold water area.

(3) The mean sea surface temperature in the whole region of the East China Sea from 1963 through 1972 was colder by 0.2°C than that from 1953 through 1962.

(4) Some periodic variations appeared in the monthly anomaly of sea surface temperature and the period of the variation seems to be of several years.

1. Introduction

The sea surface temperature is one of the most basic and important parameters of the ocean not only for hydrology but also meteorology. The Nagasaki Marine Observatory has been publishing "The Ten-day Marine Report of the East China Sea" since 1953. The Nagasaki Marine Observatory published the two volumes concerned with surface temperature in the East China Sea: "The Sea Surface Temperature of Every Ten-Days of the East China Sea in 1953 to 1957" and "The 10-Day Mean Sea Surface Temperature of the East China Sea and the Yellow Sea, 1953-1962". The present paper aims to summarize the reports for twenty years from 1953 through 1972 and to make some statistical studies on the sea surface temperature in the East China Sea.

2. Data source

The sea surface temperature for individual ten-day periods for the twenty years at 169 points shown in Fig. 1 was read on the chart of the report. The following statistical works were carried out on the basis of the 720 values at each point.

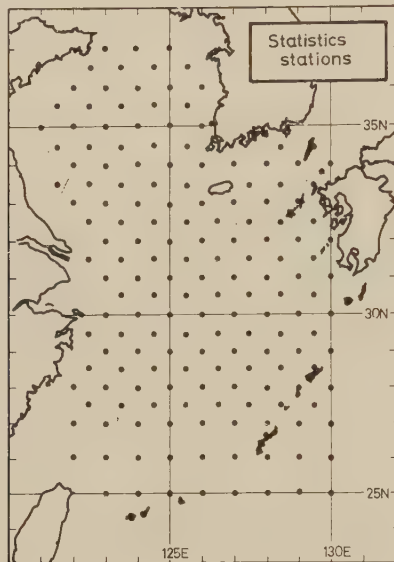


Fig. 1. Statistics stations in the East China Sea

3. Data analysis

(1) The flow pattern in the East China Sea

Fig. 2 shows the general current pattern in the East China Sea. The Kuroshio enters the East China Sea from east of Formosa and flows out to the Pacific Ocean through the Tokara straits between Yakushima and Amami-Oshima after streaming along the continental shelf. On the other hand the cold water originated along the continental coast occupies large part of the continental shelf. The Tsushima warm current branched from the Kuroshio flows northwards in the sea west of Kyūshū and flows out to the Sea of Japan through the Tsushima straits with the cold water on the shelf. The water mass of this current is formed with the mixture of those waters.



Fig. 2. Current pattern in the East China Sea

(2) Twenty-year mean sea surface temperature

Fig. 3 show ten-day, monthly, seasonal and annual mean of the temperature at sea surface for the twenty years. The distribution of the water masses can be easily

Table 1. Mean Sea Surface Temperature range in °C

	Kuroshio	Tsushima current	Cold water
Jan.	24—20	20—15	14— 8
Feb.	24—20	20—14	15— 7
Mar.	25—20	20—14	15— 6
Apr.	26—21	21—14	15— 8
May	27—23	23—17	17—12
June	29—25	25—20	20—18
July	30—27	27—24	24—22
Aug.	30—29	29—27	27—26
Sept.	29—28	28—25	26—23
Oct.	28—26	26—22	23—19
Nov.	26—23	23—20	20—14
Dec.	25—21	21—17	17—10
Winter (Jan.~Mar.)	24—20	20—14	15— 7
Spring (Apr.~June)	27—23	23—17	17—10
Summer (July~Sept.)	30—28	28—25	26—23
Autumn (Oct.~Dec.)	26—23	23—19	20—13
Annual	27—24	24—18	19—12

recognized from the pattern of isotherms. The ranges of monthly, seasonal and annual mean temperatures at sea surface for the three waters are given in Table 1.

The patterns of the isotherms at 10, 15, 20 and 25°C of the monthly mean sea surface temperature are summarized in Fig. 4.

(3) Annual range of the monthly and ten-day mean temperatures

The annual range of the monthly mean temperature at sea surface is given in Fig. 5. It is seen that the annual range in the Kuroshio region is rather small compared with that in the cold water area. For example it does not exceed 7°C in the north of Ishigakijima, whereas in the vicinity of the northern continental coast it exceeds 18°C. The maximum range is almost three times as large as the minimum one. The annual range of the ten-day mean sea surface temperature shows the same value as that of the monthly mean temperature in the warm area, but it is larger by 1.0°C in the cold region. The pattern of isorange appears to be closely correlated to the general distribution of water masses as seen in the pattern of sea surface temperature.

(4) Sea surface temperature during the twenty years at the representative stations

In order to study the year-to-year fluctuation of surface temperature six stations shown in Fig. 6 were selected to represent the following waters.

- (A) the cold water (32°N, 125°E)
- (B) the Tsushima warm current (32°N, 128°E)
- (C) the Kuroshio water at the flow-out point (30°N, 130°E)
- (D) the mixed water (29°N, 124°E)
- (E) the Kuroshio water on the continental slope (28°N, 127°E)
- (F) the Kuroshio water at the entrance to the East China Sea (25°N, 124°E)

Fig. 7 shows temperature anomaly from the monthly normal for the twenty years and Fig. 8 the 12-month running mean of them at the representative stations. It seems that some periodic variations are found in the anomaly of the sea surface temperature. It was cold in the periods of 1957, 1962-1963 and 1968, whereas in the periods of 1960, 1966 and 1971 it was warm. The temperature in the winter of 1963 was extraordinarily low. On the contrary in the winter of 1966 high sea surface temperature was observed in the Kuroshio area. Fig. 9 is an example of sea surface temperature anomaly in a cold situation (January 1963) and Fig. 10 is a warm situation (March 1966).

(5) Monthly temperature difference compared with the previous month

Fig. 11 shows the temperature change of the normal temperatures from February through March. Negative values in the figure mean that the normal temperature in March is lower than that in February. It is noteworthy that the sea surface temperature in March is above that in February in the warm water region but below in the cold water. In other months warming from April to August and cooling from September to February occur in the whole of the East China Sea. The maximum increase appears between June and July and the maximum decrease is seen between November and December. The former range less than 3°C in the Kuroshio water, from 3 to 4°C in the Tsushima warm current and more than 5°C in the cold water, and the latter ranges less than 2°C , from 2 to 2.5°C and more than 3°C , respectively. The annual variation of the monthly temperature deviation from the previous month at the four selected stations is given in Fig. 12. It is seen that at the stations A and D the rate of temperature change is large but very small at the stations B and E. The increase rate between June and May in the warm and the decrease rate between November and October in the cold water are smaller than those of the previous months. This may be the result of meteorological conditions.

(6) Standard deviation

Fig. 13 shows the departure of sea surface temperature from the monthly from 1953 through 1972 at the selected stations. The monthly standard deviation was calculated at the grid points of one-degree mesh between 25°N and 33°N from 123°E to 130°E as given in Fig. 14. The range of monthly standard deviation for each water are shown in Table 2.

Table 2. Monthly standard deviation in $^{\circ}\text{C}$

	Kuroshio	Tsushima current	Cold water
Jan.	0.6—0.8	0.6—0.8	0.9—1.2
Feb.	0.6—0.9	0.7—1.0	1.0—1.5
Mar.	0.7—1.0	0.9—1.1	0.8—1.4
Apr.	0.5—0.8	0.7—1.1	0.6—1.2
May	0.5—0.7	0.7—1.0	0.6—1.2
June	0.4—0.6	0.7—1.1	0.9—1.4
July	0.4—0.6	0.7—1.2	0.7—1.8
Aug.	0.5—0.6	0.6—0.9	0.8—1.3
Sept.	0.4—0.5	0.5—0.9	0.7—1.1
Oct.	0.3—0.5	0.5—0.7	0.6—1.1
Nov.	0.4—0.6	0.5—0.7	0.6—1.2
Dec.	0.5—0.7	0.5—0.7	0.6—1.0

The minimum of standard deviation is as much as 0.32°C in the Kuroshio in October and maximum reaches to 1.84°C in the cold water region in July. Fig. 15 shows the monthly standard deviation at the four selected stations (A, B, D and E). The standard deviation in the Kuroshio water area in the first half of the year has large values compared with those in the latter half, and throughout the year it is smaller than those in the cold waters. On the other hand, remarkable large values appear in the cold waters in the summer season. Although the water of the Tsushima warm current is formed with the mixture of the cold water and the Kuroshio water, it retains the characteristics of the Kuroshio water. The annual variation of the monthly standard deviation in the Tsushima warm current has the same tendency as observed in the Kuroshio except in July. This exception might be resulted from the effect of the cold water and the meteorological conditions.

(7) Comparison of ten-year mean temperature at sea surface between the the periods 1953-1962 and 1963-1972

For the purpose of studying the long-term trend of sea surface temperature in the East China Sea the monthly and annual average temperature were calculated for the two periods 1953-1962 and 1963-1972. Table 3 shows the departure of the monthly mean temperature averaged in the area between 25°N and 33°N lying from 123°E to 130°E in the latter period from that in the first period.

Table 3. Difference of mean sea surface temperatures in $^{\circ}\text{C}$ between the two decades, 1953-1962 and 1963-1972

Jan.	-0.16	July	-0.38
Feb.	-0.22	Aug.	+0.01
Mar.	-0.38	Sept.	-0.05
Apr.	-0.24	Oct.	-0.15
May	-0.02	Nov.	-0.03
June	-0.35	Dec.	-0.16

It is notable that the mean temperature of 1963-1972 is below that of 1953-1962 in every month except August, and even that month the departure is close to zero. Fig. 16 shows the deviation chart of the annual mean temperature in the latter period from that in the first period. In the region of the warm waters deviation is negative and positive in the area of the cold water and south of Okinawa Island. The annual change of the monthly departure is summarized in Fig. 17. From this figure it is seen that the average of 1963-1972 is below the mean of 1953-1962 with the exception from August through March in the cold

T. SAWARA: The sea surface temperature in the East China Sea

water. As a whole the annual mean sea surface temperature in the latter period is 0.2°C colder than in the former.

Acknowledgements :

The author wishes to express his sincere thanks to the members of Oceanographical Section, Nagasaki Marine Observatory for their help on calculation and also to Mr. Kawamura, Director of the observatory for his constant encouragement.

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東シナ海における 20 年間の海面水温について

佐 原 勉

(長崎海洋気象台)

西日本海況旬報に基づいて、東シナ海における 1953 年から 1972 年までの 20 年間の平均海面水温の統計を行ない、その旬別・月別・季節別及び年別の累年平均図をそれぞれ作成し、さらに若干の考察を試みた。統計方法は 720 枚の原図についてそれぞれ 1° 及び $1/2^{\circ}$ 度マス目の点における水温を読み取り、各点ごとに計算したものである。

その結果を要約すると次のとおりである。

- (1) 最高水温は東シナ海の全海域にわたって 8 月に現われる。一方最低水温の現われる時期は水系によって異なり、黒潮では 2 月であるが、大陸棚上の大陸系沿岸水では 3 月となっている。
- (2) 月平均海面水温の標準偏差は 0.3°C から 1.8°C までの範囲に広がり、黒潮域で最も小さく、また大陸系沿岸水域で最も大きい分布を示す。
- (3) 1953~1972 年の前半と後半のそれぞれ 10 年間の平均海面水温を比較すると、後者の方が 0.2°C くらい低くなっている。
- (4) 各年各月の月平均海面水温の偏差の変動からみると、数年を周期とする周期性らしいものが認められる。

Fig. 3. Distributions of twenty-year mean sea surface temperature

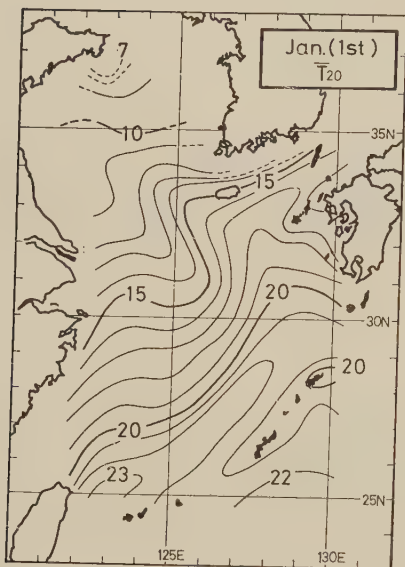


Fig. 3-1. The first ten-day of January

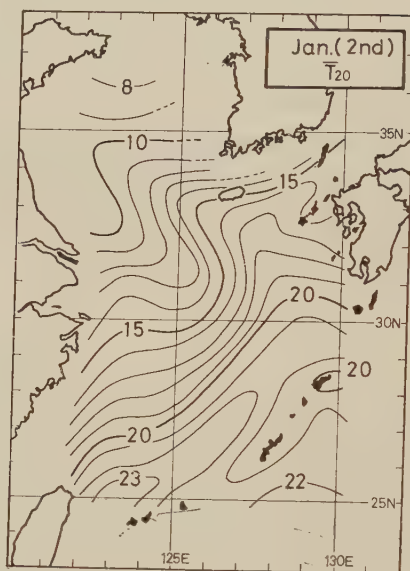


Fig. 3-2. The second ten-day of January

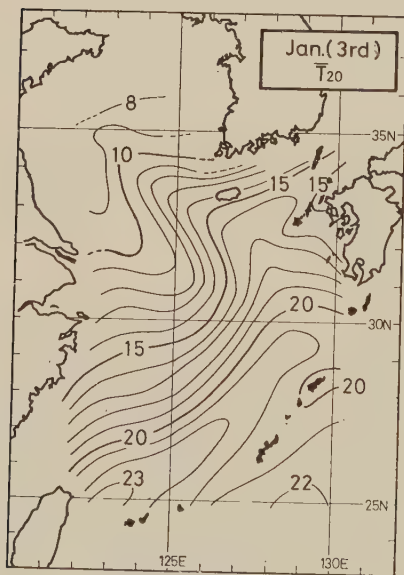


Fig. 3-3. The third ten-day of January

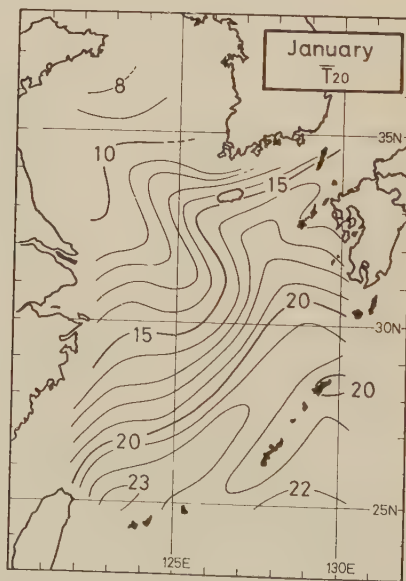


Fig. 3-4. January

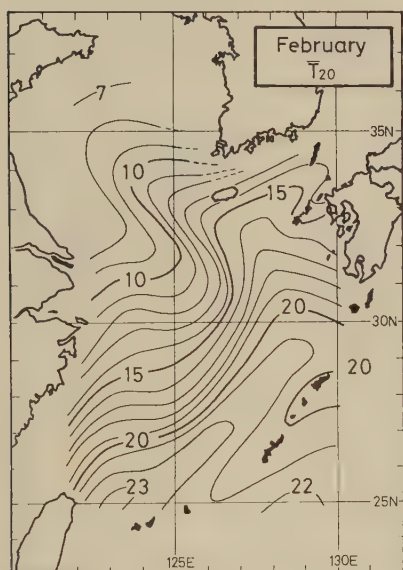


Fig. 3-5. February

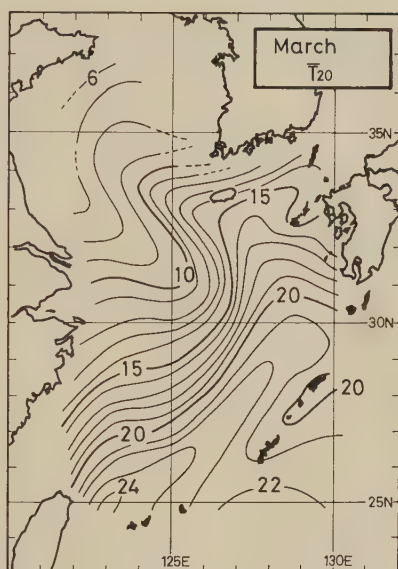


Fig. 3-6. March

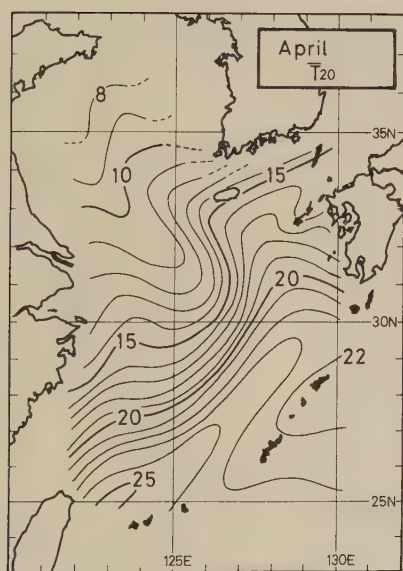


Fig. 3-7. April

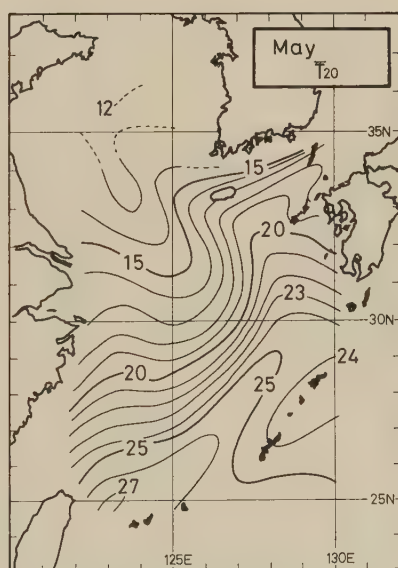


Fig. 3-8. May

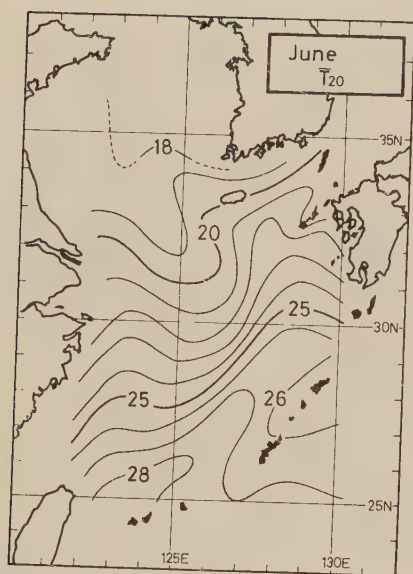


Fig. 3-9. June

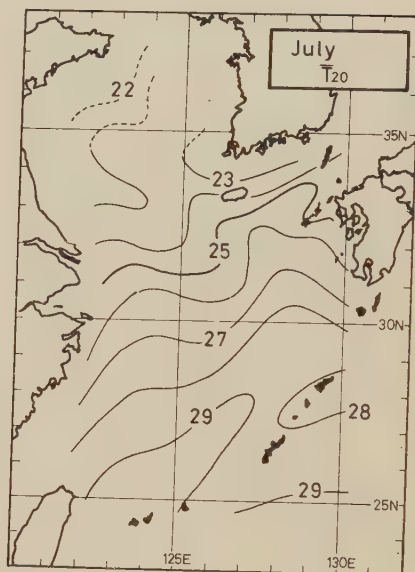


Fig. 3-10. July

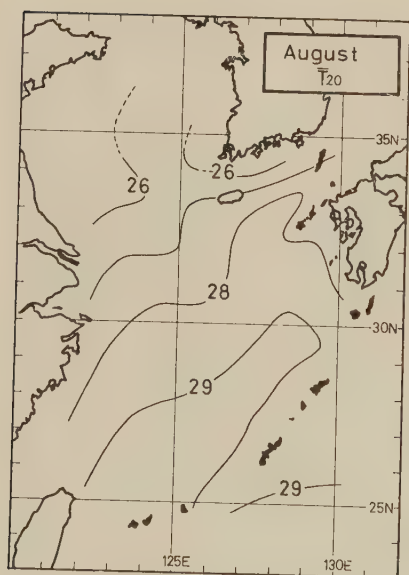


Fig. 3-11. August

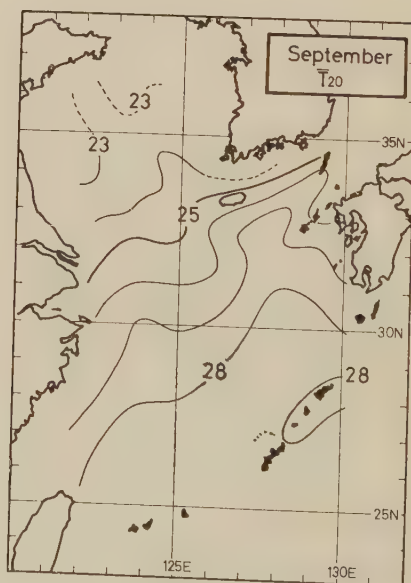


Fig. 3-12. September

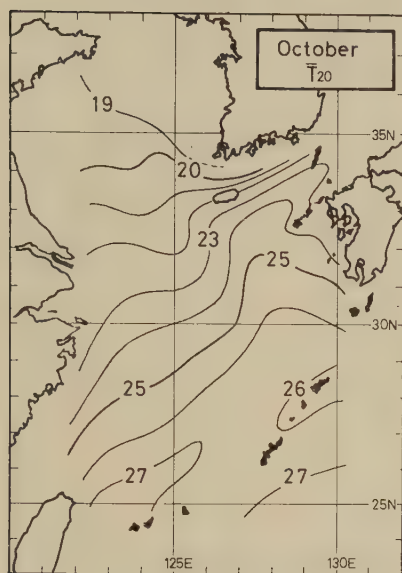


Fig. 3-13. October

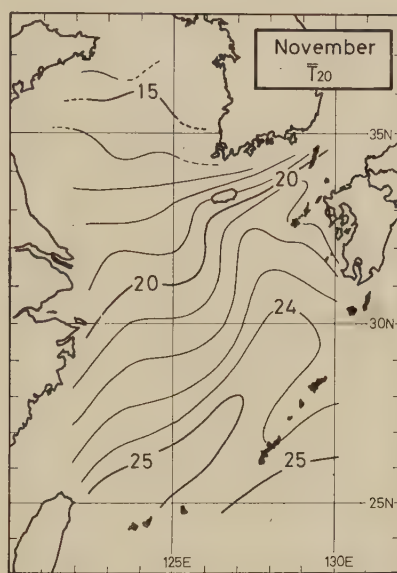


Fig. 3-14. November

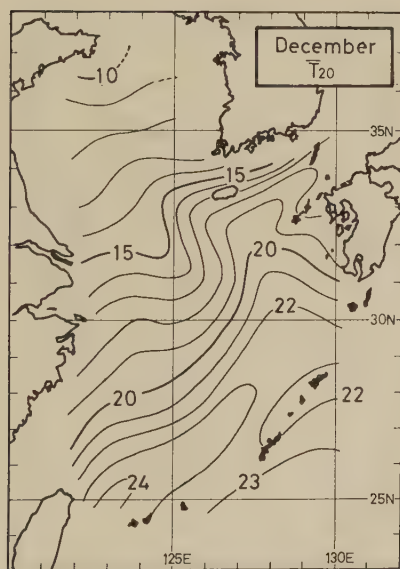


Fig. 3-15. December

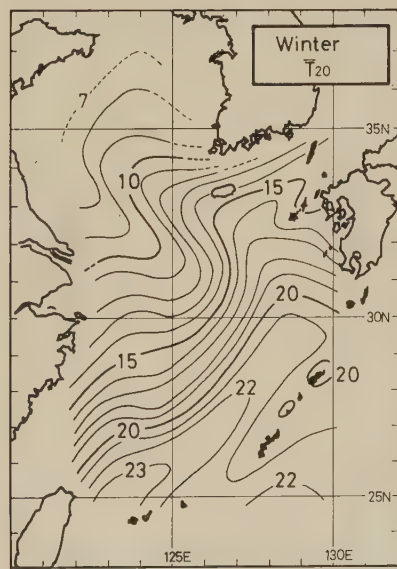


Fig. 3-16. Winter (January-March)

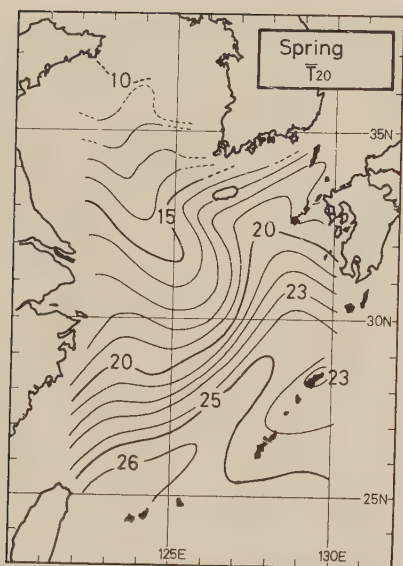


Fig. 3-17. Spring (April-June)

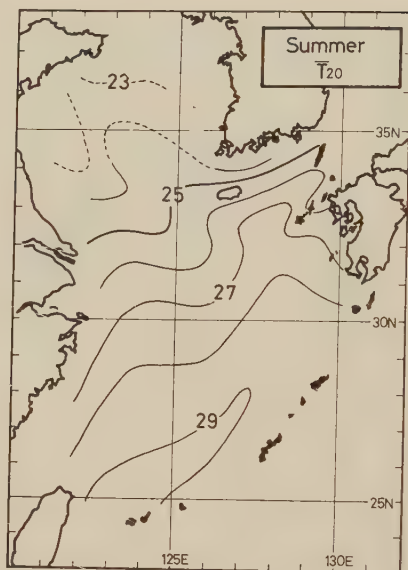


Fig. 3-18. Summer (July-September)

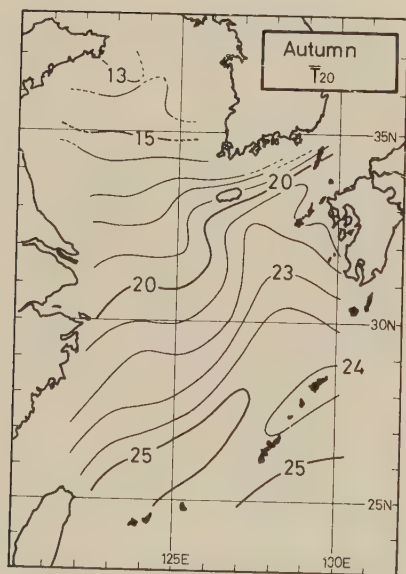


Fig. 19. Autumn (October-December)

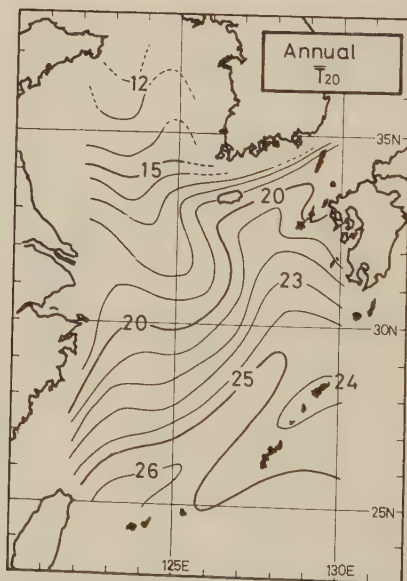


Fig. 3-20. Annual mean

Fig. 4. Movement of isothermal lines (monthly mean temperature)



Fig. 4-1. 10°C and 15°C

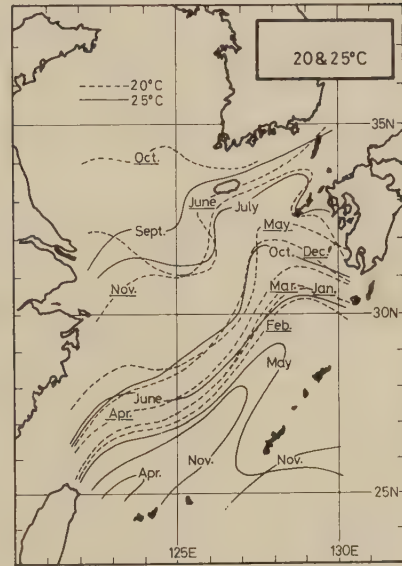


Fig. 4-2. 20°C and 25°C

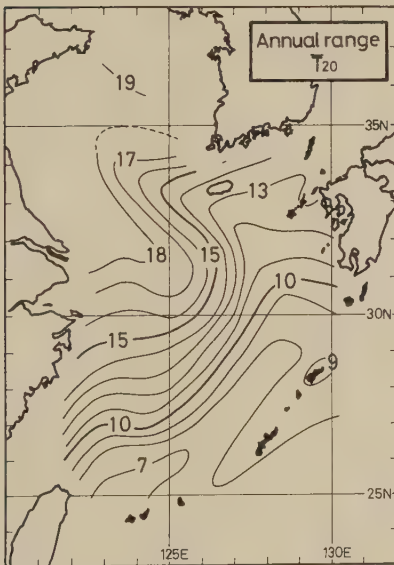


Fig. 5. Distribution of the annual range of twenty-year monthly mean sea surface temperature

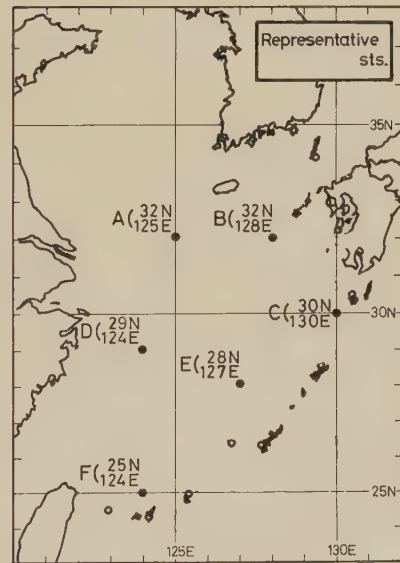


Fig. 6. Representative stations in the East China Sea

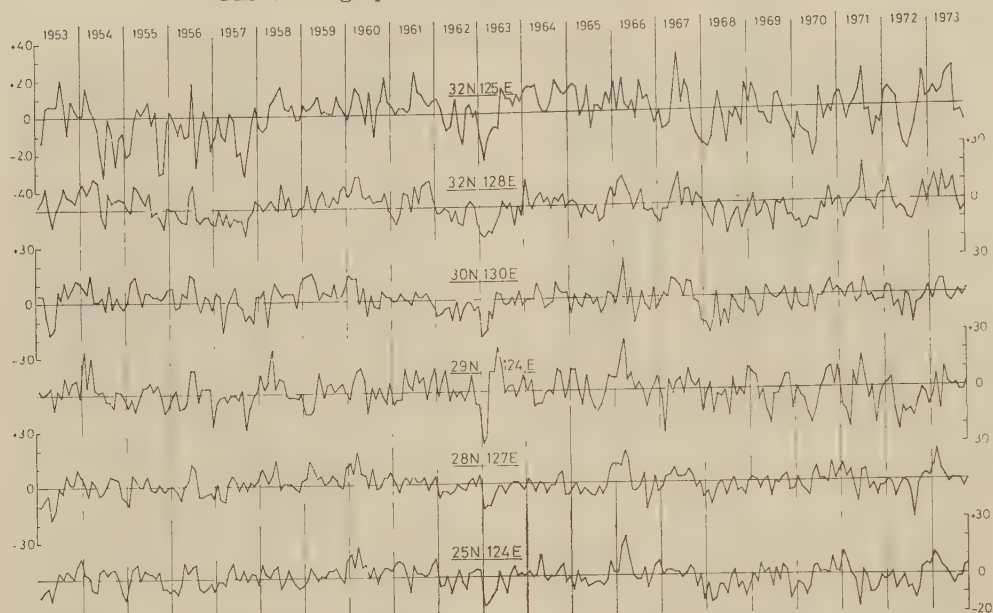


Fig. 7. Distributions of deviation from twenty-year mean sea surface temperature

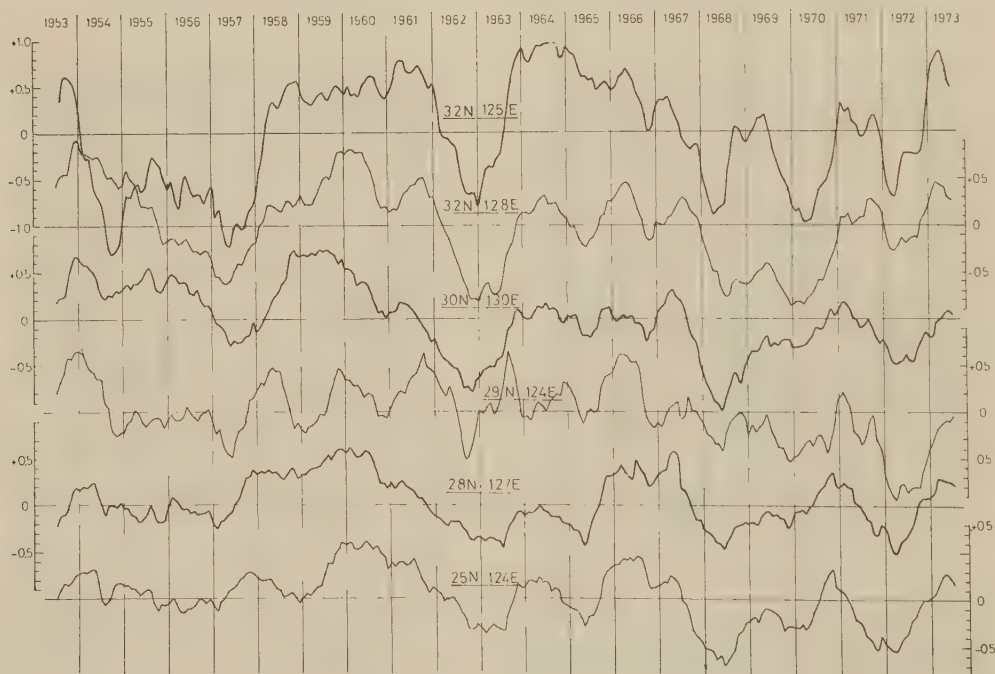


Fig. 8. Distributions of twelve-month running mean of deviation from twenty-year mean sea surface temperature

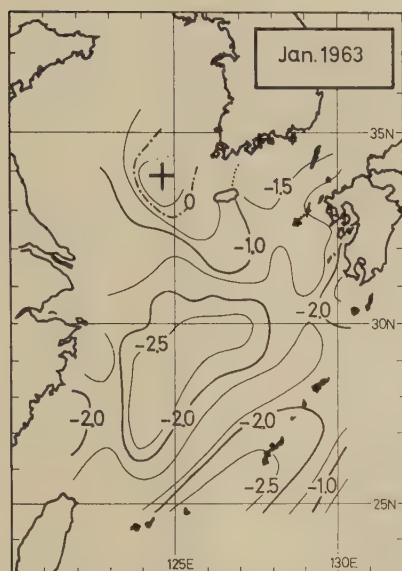


Fig. 9. Distribution of deviation from twenty-year mean sea surface temperature in January 1963 (example of low temperature)

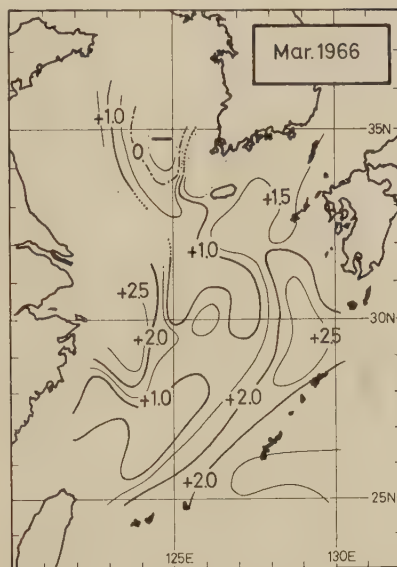


Fig. 10. Distribution of deviation from twenty-year mean sea surface temperature in March 1966 (example of high temperature)

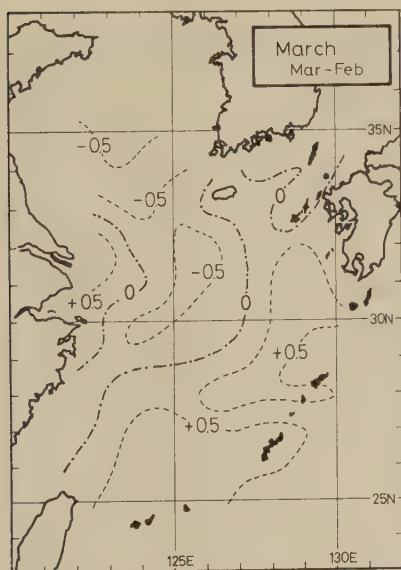


Fig. 11. Distribution of difference from the previous month's twenty-year mean sea surface temperature in March

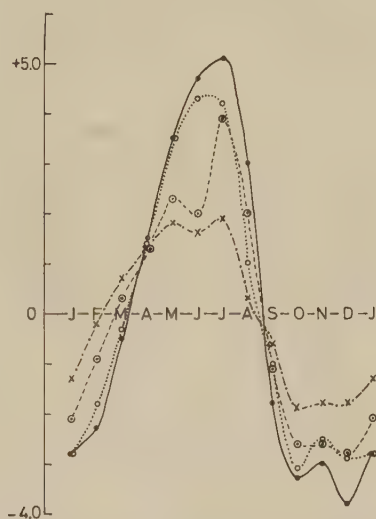


Fig. 12. Seasonal change of difference from the previous month's sea surface temperature on every month at the four selected stations (A, B, D, E)

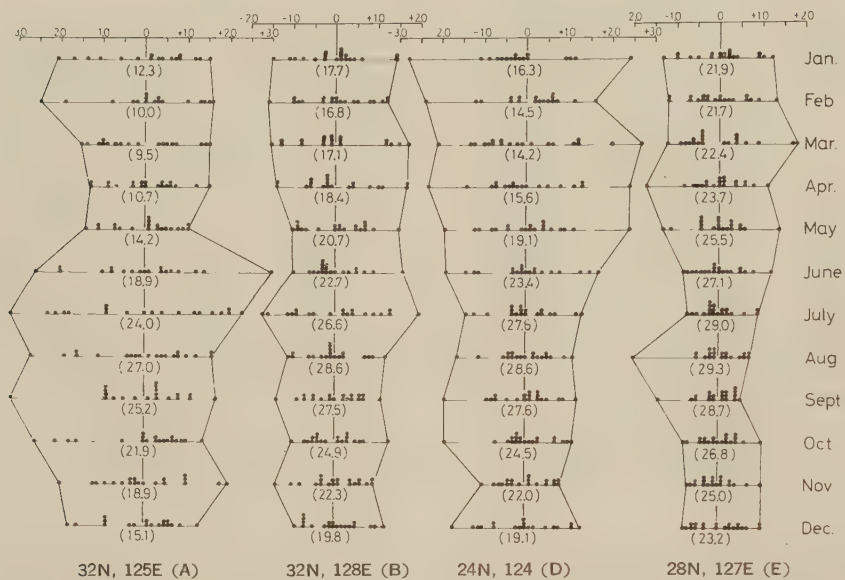


Fig. 13. Distributions of deviation from monthly mean sea surface temperature at the four representative stations
(): monthly mean sea surface temperature

Fig. 14. Distributions of standard deviation of sea surface temperature

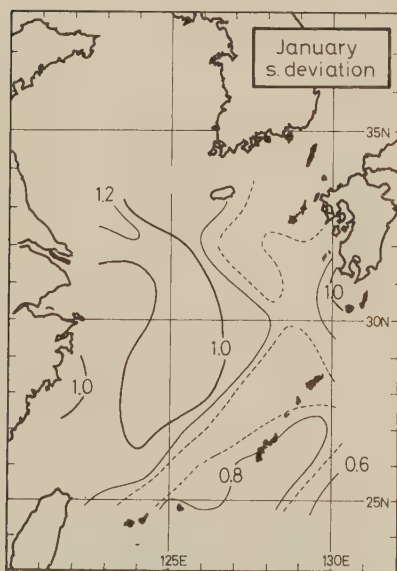


Fig. 14-1. January

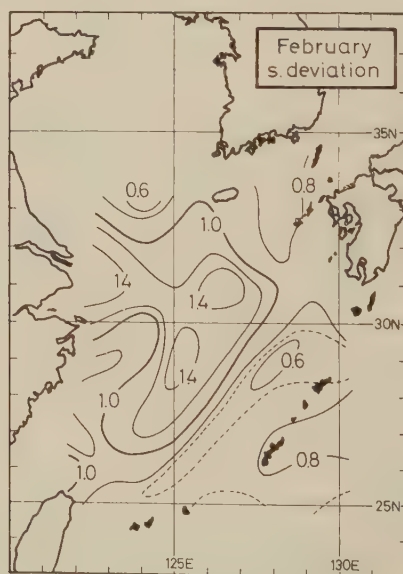


Fig. 14-2. February

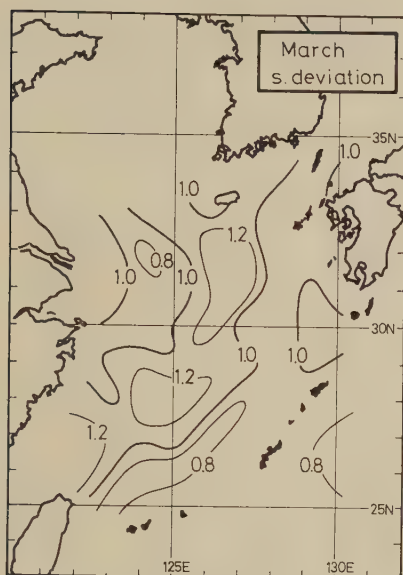


Fig. 14-3. March

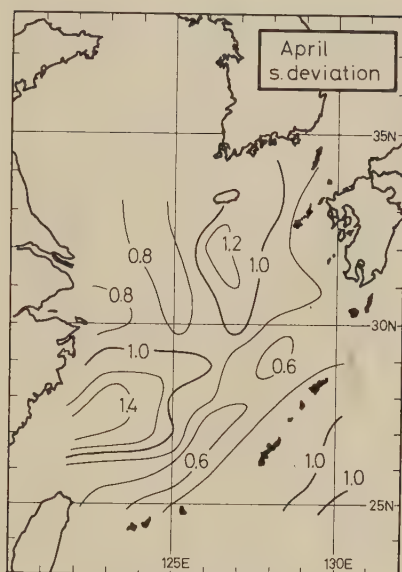


Fig. 14-4. April

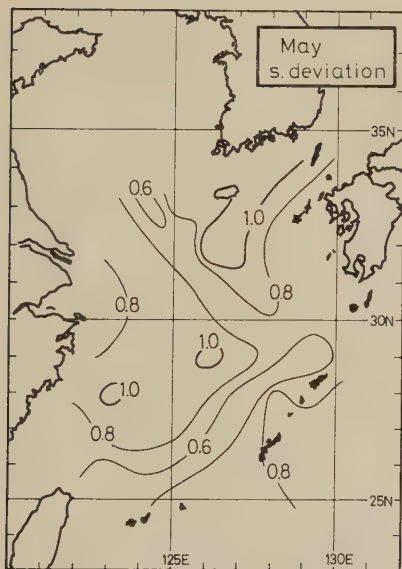


Fig. 14-5. May

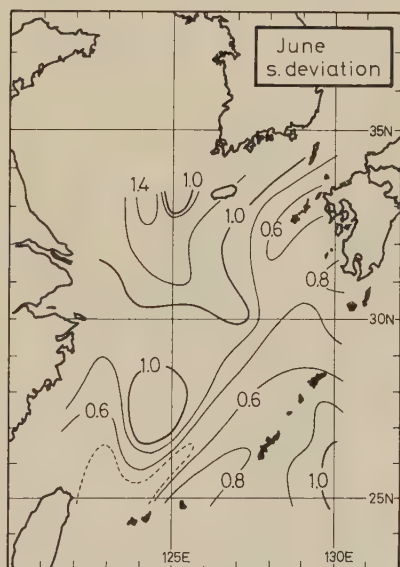


Fig. 14-6. June

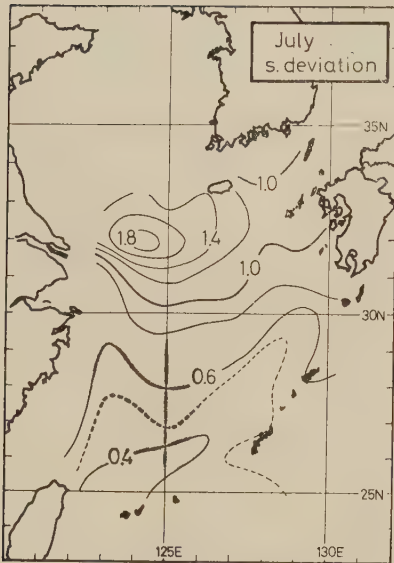


Fig. 14 7. July

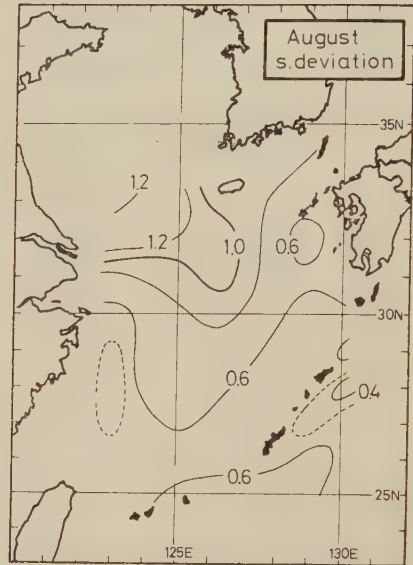


Fig. 14 8. August

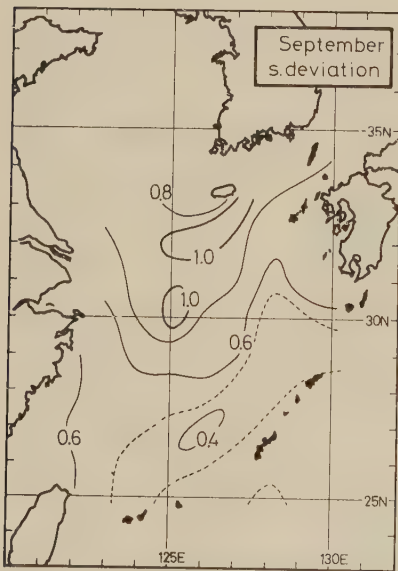


Fig. 14-9. September

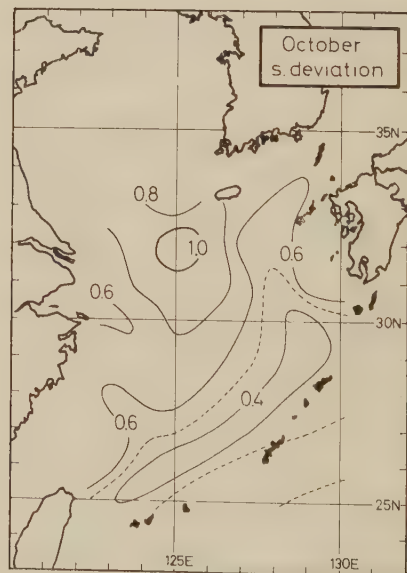


Fig. 14-10. October

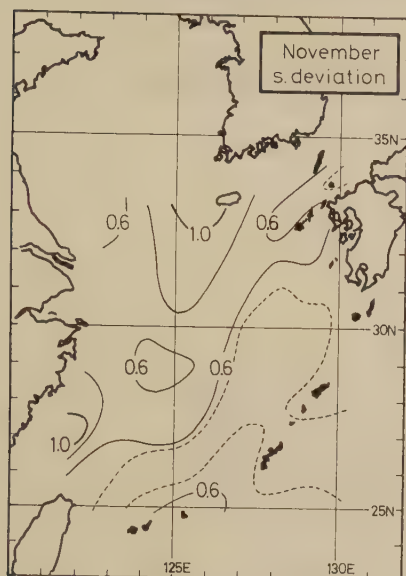


Fig. 14-11. November

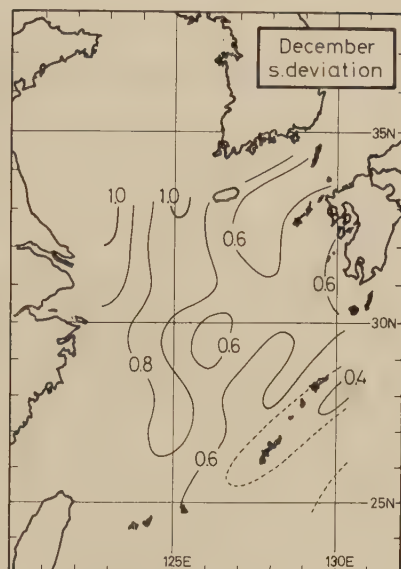


Fig. 14-12. December

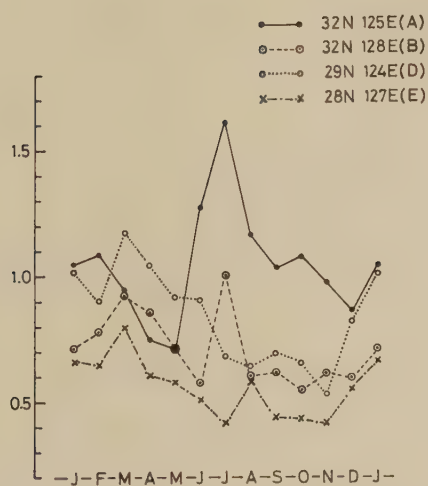


Fig. 15. Monthly change of standard deviation at the representative stations

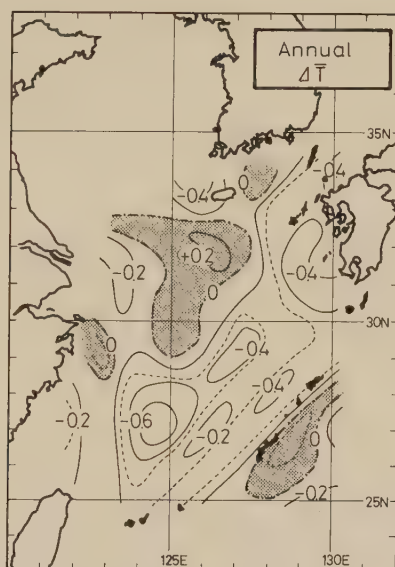


Fig. 16. Distribution of difference on annual mean sea surface temperature of the first and the latter half ten years

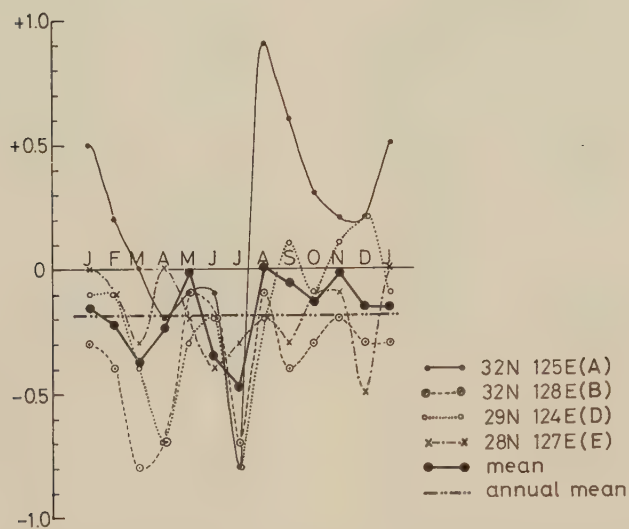


Fig. 17. Monthly change of difference between the first and the latter half ten-year mean sea surface temperature at the representative stations

Newly-built research vessel Shumpu-Maru III

Koichi NAGASAKA

Japan Meteorological Agency

(Received October 5, 1974)

The Shumpu-Maru III is a newly-built research vessel operated by Kobe Marine Observatory. She has replaced the Shumpu-Maru II and is the third ship under the same name. The Shumpu-Maru II was built in March 1954 at Nippon Kokan Shimizu ship yard and pioneered the Japanese research vessel electrizing by the alternating current power. She had engaged numerous research cruises logging up 239,000 miles by the time she retired in March 1974.

The new Shumpu-Maru was keeled in August 1973, launched in January 1974 and delivered in March 1974. She was built by the Ishikawajima-Harima Heavy Industries Company, Tokyo, at a cost of four hundred and fifty million yens. She is not only larger than the older ship but also designed to meet contemporary requirements for oceanographic and meteorological investigations in the seas adjacent to Japan. She is already on service since April 1974.

The characteristics of the Shumpu-Maru III are summarized as follows.

(1) Particulars

She is 48.50m long overall, 44.00m between perpendiculars and has a beam of 7.80m, a depth of 3.90m and a draft of 2.95m. Her gross tonnage is 373.11 tons. She has a range of 7,000 miles with a cruise speed of 11.4 knots. She recorded maximum speed of 12.48 knots on trial.

(2) Accommodations

All living and working spaces except the wet laboratory are air-conditioned. She can carry 81.56 tons of fresh water. She has 15 cabins with single, double and four berths and six of them are for eleven officers, four for fifteen seamen and five for thirteen scientists. The anti-rolling-tanks are equipped along both sides of the engineroom.

(3) Propulsion

A three-braded variable-pitch propeller is driven by a four-cycle super-charged diesel engine (Daihatsu, 6 PSHTCM-26E). The rated power of the engine is 640 H.P. at 680 r.p.m. and the maximum output is 750 H.P. at 720 r.p.m. The capacity of fuel tank is 92.70 tons. The ship-speed can be controled in the wheel house as well as in the engine monitoringroom.

(4) Electrical power

She has two sets of generators rated AC 80 kVA, 450V, 60 Hz (3 phase) which are driven by two diesel engines rated at 130 P.H. at 1,200 r.p.m. Power source of 1.1 kW stabilized in the range of 100 ± 10 V and 60 ± 1 Hz is available for scientific works.

(5) Navigation and communications equipment

For navigation she is equipped with a gyrocompass, a magnetic-compass, an automatic piloting system, a depth sounder, an electro-magnetic log, a receiver for LORAN A and C and two sets of radars. Two sets of short and medium wave transmitters and three sets of allwave receivers are equipped for radio communication.

(6) Equipment for scientific works

The following is a summary of scientific equipment.

(A) Echo-sounder

Frequency	25 kHz
Output	30 kW
Max. sounding range	6,000 m

(B) Oceanographic winches

Hydrographic winches

Hydraulic	wire : 5,000 m, 3.0 mm ϕ , 6.9 H.P.
Electric	wire : 2,000 m, 3.0 mm ϕ , 3.7 kW (AC)

BT winch

Electric	wire : 1,500 m, 2.1 mm ϕ , 2.2 kW (AC)
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GEK-Cable winch

Electric	GEK-Cable : 250 m, 2.0 kW (AC)
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K. NAGASAKA : Newly-built research vessel Shumpu-Maru III

(C) Laboratories

Wet laboratories	sheltered	10.5 m ²
	unsheltered	9.4 m ²
Dry laboratories	oceanographic	26.1 m ²
	meteorological	7.1 m ²

(D) Scientific instruments and equipment regularly carried

Nansen's water bottle and reversing thermometer	1.2 1 type, 25 sets
	2.0 1 type, 10 sets

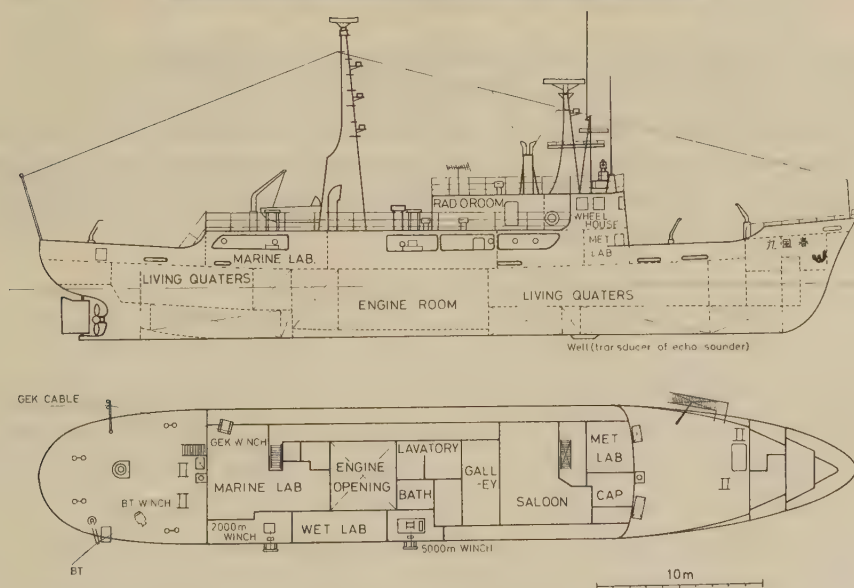


Fig. 1. Newly-built research vessel Shumpu-Maru III

GEK	1 set
STD	2 sets
X-BT	1 set
M-BT	4 sets
Surface salinity and temperature recorder	1 set
Inductively coupled salinometer	1 set
pH meter	1 set
Photoelectric colorimeter	2 sets
Hauling nets for plankton collection	various
Mini-computer (8 kW)	1 set
Ordinary maritime meteorological instrument	1 set
Facsimile receiver for weather map	1 set
Tucker-type wave recorder	1 set

新 観 測 船 春 風 丸 III

長 坂 昂 一

(気象庁)

気象庁では、老朽化した春風丸 II (150 t) の代船を昭和 48 年度に建造中であったが、昭和 49 年 3 月に完成し、同年 4 月から神戸海洋気象台の観測船として就航を開始した。本船は、日本近海の海洋・海上気象観測を対象として建造され、全長 48.5 m、総トン数 373.11 t で、推進器として一軸 (750 馬力) の可変ピッチプロペラを装備している。独立した海洋観測室及び海上気象観測室が各々一室設けられ、又海洋観測用ウインチとしては 5,000 m (3mm ϕ)、2,000 m (3mm ϕ)、BT、GEK コード用の 4 台が装備されている。

Abnormal spreading of cold water along the east coast of Honshyu Island in February, 1974

Hayato IIDA and Kiyoshi KATAGIRI

Japan Meteorological Agency

(Received October 10, 1974)

Abstract: The first branch or coastal branch of the Oyashio which has a great influence on climate and fisheries in the coastal sea area east of Japan, has become stronger and wider, and extended southwards since April of 1973 after a weak period of several years.

The branch became especially strong and wide in the winter of 1974, and thin layer of cold and low salinity water due to melting of sea ice from the Okhotsk Sea was carried towards the coast of Honshyu Island, with its properties unchanged, on the cold belt of the first branch by the northerly wind which was especially strong in the northern part of Japan. The water killed thousands of fishes and seaweed and gave rise to freezing of coastal waters seldom seen around there.

In general, amounts of drift ice from the Okhotsk Sea to the Pacific Ocean or the local wind direction and strength around the sea area, are not always related to the strength of the first branch of the Oyashio. The change of its strength occurs every 3 to 7 years. Such period is also found in large-scale phenomena of the atmosphere and ocean. Therefore, the change of pattern of the Oyashio branch should be considered to be a local manifestation of such large-scale phenomena.

1. Introduction

In the morning of February 25, 1974, a great amount of fishes were found washed ashore along the coast of Kesen'numa, Miyagi prefecture, and further thousands of dead fishes such as ushihamo and umazurahagi were floating on the sea surface. It was due to the sudden decrease of water temperature caused by the sudden approach of cold water towards the coast. Thereafter, in March, freezing of sea water occurred helped by lowering of salinity along the northeastern coast of Honshu Island where the Tsugaru Warm Water flows southwards usually,

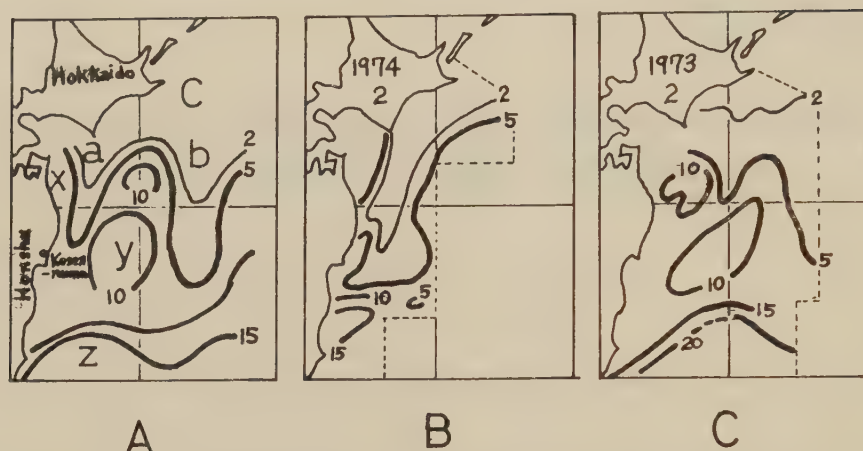


Fig. 1. The patterns of the first branch of the Oyashio, (A) normal pattern; a, the first branch, b, the second branch, c, the Oyashio water, x, the Tsugaru Warm Water, y, warm water masses, and z the Kuroshio Extension, (B) February, 1974 and (C) February, 1973.

and gave big damage to cultured seaweed.

From the first of February the R/V Kofu Maru (346 t.) of Hakodate Marine Observatory was making her routine cruise for oceanographical observations, and found the cold water below 2°C had spread south to southwestwards from the sea southeast of Hokkaido (Fig. 1-B).

The cold water is the so-called Oyashio water made up in the subarctic region south of the south Kurile Islands during winter by convection, and remains as the so-called intermediate cold water in the depths, 100 to 200 m, in the warmer seasons. From the Oyashio water, cold water belts usually branch off southwards into warm water masses sheared from the Kuroshio Extension. The first or the coastal branch is usually found between the Tsugaru Warm Water (x in Fig. 1-A) and warm water masses (y), and the second or the offshore branch is east of the warm water masses and so on. The pattern is changing year by year. If the warm water masses are located near the coast, the first branch becomes narrow and meager while, if they are far offshore or very small, the first branch becomes wide and grand.

The temperature difference between the warm waters and the Oyashio water in the branches is about 5 to 10°C , so the change of pattern affects the fisheries in the sea east of Japan and coastal climate.

In order to show the change of pattern, 100 m temperature charts are used



Fig. 2. The change of the isotherms at the 100m depth from November 1972 to August 1974 (hatch area shows the Oyashio region).

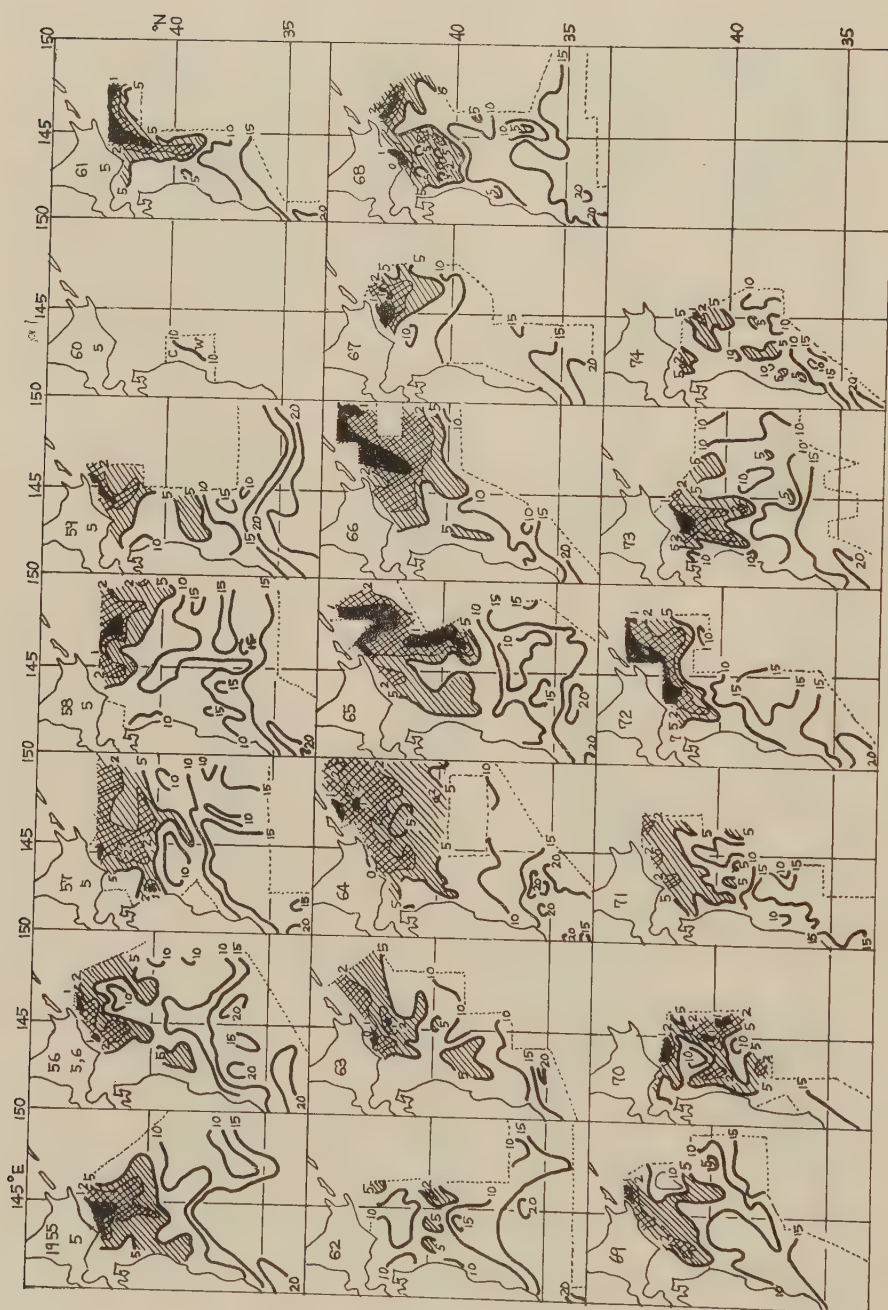


Fig. 3. The change of the isotherms at the 100 m depth in spring from 1955 to 1974.

usually (Figs. 2 and 3). As the 100 m temperatures in the water masses appeared in the sea region shown in the figures scarcely show seasonal changes, their distribution is very useful for identifying the change of pattern, although most appropriate depth is supposed to be between 100 and 150 m.

The change of the pattern signified by the intensification of the first branch occurred in April-May 1973, as seen from Fig. 2 (IIDA, et. al. 1974). Before the spring of 1973, the warm water masses sheared from the Kuroshio Extension used to be located near the coast and the first branch was very weak and narrow or hardly seen sometimes (Fig. 1-3).

2. The change of pattern and sea surface temperature

Fig. 3 shows the change of pattern by 100m temperature since 1955. The change of pattern seems to occur every 3 to 7 years, that is, the pattern in which the first branch is strong and wide, occurred in 1955 to '57, '63 to '66 and since April of 1973. The weak and narrow pattern occurred in 1958 to '60, '62 and '67 to the winter of 1973. The change of pattern also appears in the sea surface tempera-

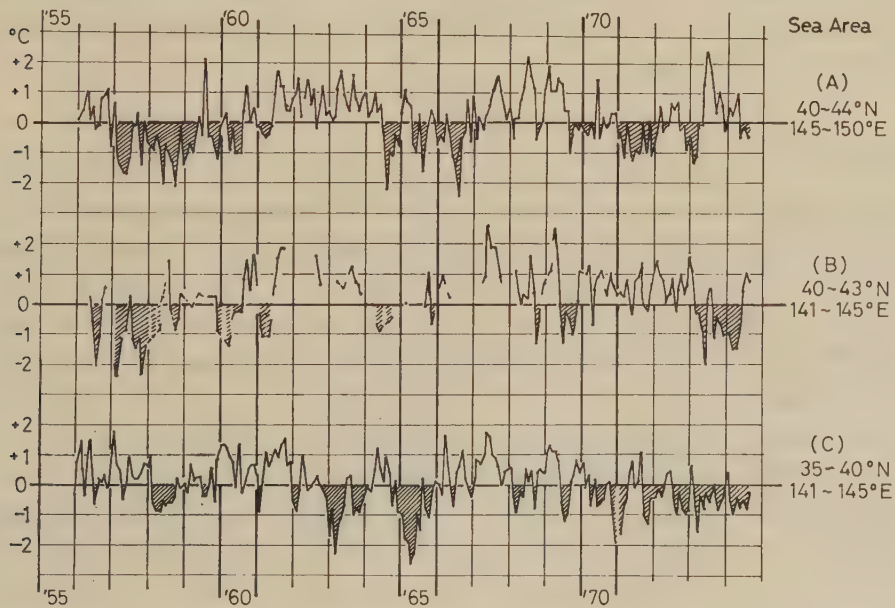


Fig. 4. The SST anomalies in the areas (A) the Oyashio water, (B) the northern part of the first branch of the Oyashio, and (C) the southern part of it.

ture (SST) anomaly shown in Fig. 4. In the figure, the anomalies of monthly mean SST in the areas (A) 40° to 44° N, 145° to 150° E: The Oyashio region, (B) 40° to 43° N, 141° to 145° E: the northern part of the first branch, and (C) 35° to 40° N, 141° to 145° E: the southern part of the branch, are plotted for 1956 and after.

The change of pattern corresponds well with the anomaly changes in (B) and (C) when the changes in those areas are considered in combination. In 1956 and '57, the SST was low in the northern part, in 1963 and 1965 it was low in the southern part, in the spring of 1973 to 1974 it is low in both areas, and so on. In these areas, the anomaly changes are mostly due to the change of the pattern.

The anomaly change is very regular in the Oyashio region (A), and the several year periodicity is easily seen from the figure, but less regular in (B) and (C), the first branch, where the effects of the Kuroshio water and the Oyashio water are combined. Good correspondence among the anomaly changes in the three areas are hardly found, although a periodicity of several years is obtained by spectral analysis (IIDA, et. al., 1974). Between (A) and (B), rather better correspondence is found before 1969, but after 1970 the correspondence becomes inverse. Between (B) and (C), no correspondence is found. The same tendencies are found in the figure by FUKUDA (1940) who also found a 7-year periodicity which is most significant around (B) and (C).

3. Discussion

Some suggestions on the cause of the pattern change have been advanced since the beginning of this century. One is stronger northwesterly monsoon in winter makes the first branch stronger and wider. Another is large amount of the drift ice from the Okhotsk Sea through the straits among the south Kurile Islands makes the first branch wide, cold and strong. But there are no significant correspondence between the local wind or the amount of drift ice and the strength of the first branch. In fact the years when the amount of the drift ice in the sea east to southeast of Hokkaido was large, are 1955, '56, '60, '61, '63, '64, '70 and '74 (AKAGAWA, 1963, JMA, 1961 to 1967). It is difficult to find the correspondence to this. As one pattern continues several years, the change of pattern should be considered as a manifestation of large-scale phenomena in the ocean and atmosphere.

Acknowledgement:

The author wishes to express hearty thanks to the members of Oceanographical Section of JMA.

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本州東方沖における冷水域の異常南下について

飯田隼人および片桐清之

(気象庁)

1974年の冬、冷水が三陸沿岸に異常接近し、同沿岸で魚介類のショック死、また、この水が低塩分であるための珍しい結氷現象による海草の枯死等の被害が起って大問題になった。

これは 1973 年春季以来強勢になっていた親潮第一分枝の上に、例年より強勢の北寄りの風により、大量に太平洋に流出していた海水から融けて出来た低温・低塩分の水がごく薄い層をなして、三陸沿岸に接近、岸寄りを幅狭く流れている津軽暖流の上おも覆って湾内にまで侵入してきたためと考えられる。

このように沿岸の気象・漁業に重要な役割を果している親潮第一分枝は、黒潮の第一の山から分離して、北～北々東に移動する暖水塊の位置やその大きさにより、その面積や位置が変動する。この親潮のパターンの変動は 3～7 年おきに起きているようである。このことは、同海域の平均水温の平年偏差の変動にも現われている。

このパターン変動の原因に関しては、昔から諸説があり、あるいは、北海道・三陸近海における季節風の強弱による、あるいは、オホーツク海から太平洋への海水の流出量の多少による等としていた。しかし、これ等局所的な原因との間には、あまり顕著な対応は見られない。一方、全大洋・大気の大規模な現象中にも同様な周期的変動が見られる。したがって、大規模な現象の局所的現われと見るのが妥当であろう。

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